WAVES AND VORTICES ON A QUASI-STATIONARY BOUNDARY SURFACE OVER EUROPE

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A review[1] by H. WILLETT

This paper contains a thorough analysis of the weather situation over central Europe from October 8 to 13, 1923, and a rather brief study of the distribution of the meteorological elements in the air masses throughout the region under consideration. The authors do not go into the elementary details of the problem of establishing the position of the boundary surface between the air masses of polar origin and those of tropical origin in the present situation. They are concerned rather with the phenomena which develop and travel along this front. Furthermore, on their charts they include no data that seem to be subject to local disturbing influences which render the observed values of the meteorological elements non-representative. Hence on these charts the situation appears more clear-cut and simple than it really is.

The developments which lead to the establishment of the quasi-stationary front may be briefly traced as follows. An area of low pressure has moved slowly across the north Atlantic Ocean towards the coast of Norway, where, as it began to fill up, a secondary formed to the south. This caused a pronounced trough, the mother depression of the series of cyclonic phenomena under discussion. Behind this depression the polar air spread out in several waves in an east-southeast direction. But those waves did not work further south than about latitude 49°, along which they moved. To the south, extending from the Azores eastward over southern France, was a marked Azores HIGH, almost stationary, which gave rise to a vigorous west-southwest air current of tropical origin extending up to the forty-ninth parallel. Hence, by the morning of October 10, along approximately this parallel, we have a marked discontinuity between two air currents of polar and tropical origin. Equilibrium conditions along this front are satisfied, for it remains practically stationary for 48 hours, extending throughout the field of observation from about longitude 15° west to 30° east, or more. Along much of this front we have ascending air motion and warm front rain, with the typical warm front cloud formations.

The first disturbance on this front to be studied is a so-called wave disturbance (Wellenstörung). A degenerate cyclone moves, during the 10th and 11th, across the North Atlantic within the polar air. The longitudinal component of the circulation around this weak center results in the development, on the front, of a distinct warm sector (or protrusion northward of warm air), followed by a cold sector in the rear. The disturbance moves rapidly from west to east along the front, but due to the lack of any vigorously southward moving cold air masses behind the warm sector to effect occlusion, it remains flat and open. The transition from tropical air (warm west-southwest wind) to polar air (cold west-northwest wind), is everywhere very abrupt and marked—a true discontinuity. The wind velocities are everywhere high, but highest in the warm sector. The disturbance as a whole moves eastward along the front much faster than the air itself is moving, or than the disturbance which caused it. Hence it appears to move as a true wave along the boundary of air masses of different density, and, once having been generated, it seems to be independent of the parent cyclone. Behind the disturbance the front is completely restored to its original condition. Several other smaller disturbances move along the front as waves, having true (though very small) warm and cold sectors, with abrupt transitions and wind shifts.

By the morning of the 11th the second principal disturbance makes its appearance over the western portion of the front. It originates, like the wave disturbance, under the influence of a cyclone in the polar air far to the north, which gives rise to a warm sector in the front. But the further development is very different. In this case the disturbing cyclone is much more vigorous, with an extensive mass of southward moving polar air behind it. This cold air, pushing into the circulation of the front, thus increases the circulation around it, and effectively occludes the warm sector. Hence this disturbance develops into one of the vortex type, not remaining merely a wave on the front. It becomes eventually independent of the front on which it was generated. As a result of the increased vortical circulation, the front between the polar and tropical air masses loses its very sharp outline. In this disturbance the transition from warm air to cold air, from west-southwest to west-northwest winds, is much less abrupt than in the case of the wave disturbance, as shown by thermographs and wind direction traces. There is a wavelike irregularity in the traces which indicates that the cold air arrives in successive small waves, or that the front, is now made up of a succession of small fronts or layers. This disturbance eventually moves away from the front far into the polar air mass to the northeast, becomes occluded, and joins the mother depression over northern Norway. Its passage destroys the equilibrium on which the maintenance of the front depended. Hence the cold air masses behind the disturbance, spreading southward and eastward, eventually reach the general trade wind circulation, displacing the monsoon LOW over the Egyptian Sudan 5° to the south, and finally ending that particular family of cyclones. The next family, according to the Bergen School, must start with a new and distinct front far to the north.

In their introductory remarks the authors compare briefly the Bergen theory of the origin and maintenance of cyclones (that each cyclonic family is a series of waves in various stages of development on a separate front), with the so-called Barrier theory of Exner (Riegel theorie der Zyklogenese). According to this theory LOWS are formed in the lee of masses of heavy polar air spreading southward into swiftly moving westerly winds of tropical origin. Although Bergeron and Swoboda do not definitely deny the possibility of explaining some cyclones on that theory, they suggest a number of difficulties in it. The chief objection to the Bjerknes wave theory, namely, that no one has ever shown a cyclone to be truly a wave on a front between air masses of different density, or that waves of such an implitude are possible, they regard as answered by their analysis. This, they believe, proves almost conclusively that disturbances of a truly wavelike nature arise in the case under discussion. Even the disturbance that destroyed the front had that origin. But the authors make no statement as to whether all cyclones can be so explained, although that is the theory they seem to wish to establish. This theory as a universal explanation of cyclonic development seems inadequate, but it does appear to fit the phenomenon of cyclone families better than Exner's barrier theory.

[1] "Wellen and Wirbel an einer Quasistationären Grenzflache über Europa," Veröffentlichen des Geophysikalischen Instituts der Universität, Leipzig, Bd. III, Heft 2, by Bergeron and Swoboda.

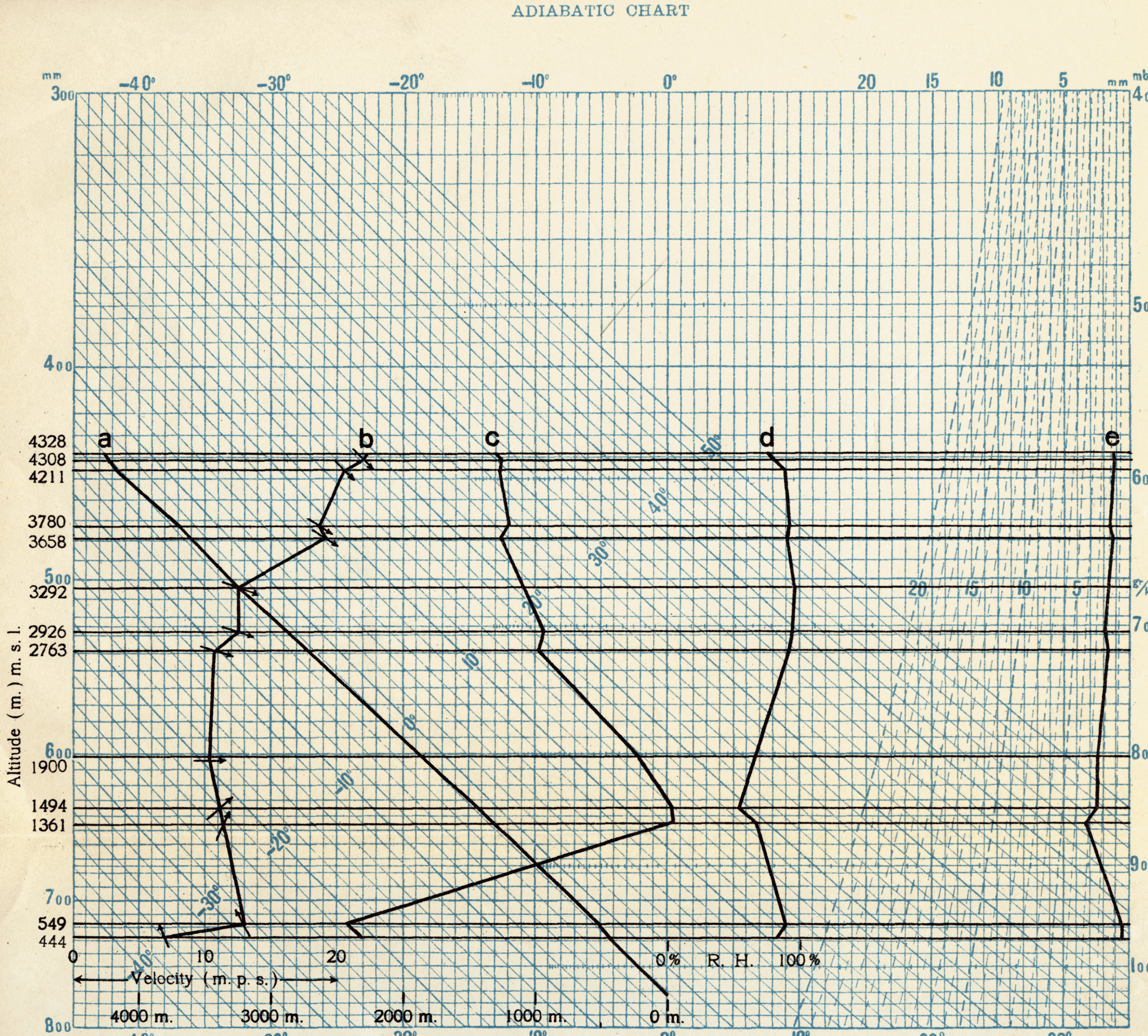

FIG. 1.—Graphical representation of kite record from Ellendale, N. Dak., February 2, 1925. (*a*) Pressure-height curve referred to height scale along abscissae axis; (*b*) pressure-wind curve, showing velocity and direction; (*c*) pressure-temperature curve; (*d*) pressure-relative humidity curve; (*e*) pressure-vapor pressure curve. Figures along ordinate scale on left side are obtained from pressure-height curve, and indicate the altitudes of the points at which the lapse rate changes. Small vertical lines on the even pressure lines indicate amount of correction to be applied to actual temperature to obtain virtual temperature. Broken lines running upward along right side of graph are specific humidity curves. Upper right abscissae are vapor pressures. Diagonal full lines from lower right to upper left are dry adiabatics, and give the potential temperature (°C.) referred to standard pressure of 1,000 mb. Ordinates are logarithms of pressure (mm. on left, mb. on right). Upper and lower abscissae are Centigrade temperatures. Form No. 1126-Aer. is a reproduction of the form used by the Lindenberg Observatory.

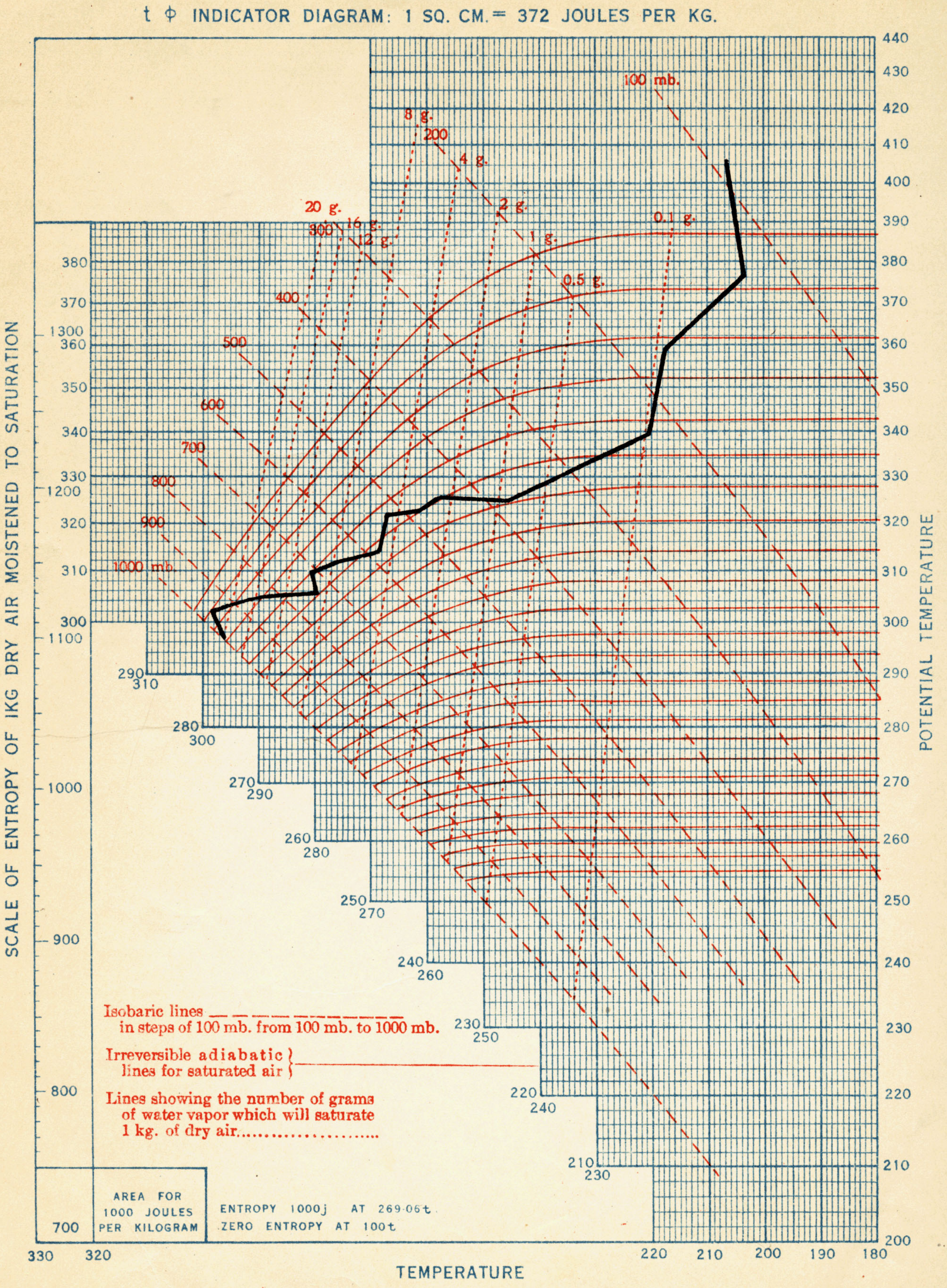

FIG. 2.—Tephigram of balloon sounding. Royal Center, Ind., May 6, 1926. The graph is constructed by computing potential temperatures from Poisson's Equation and plotting them as ordinates, with the actual temperatures at corresponding levels as abscissae. Actual pressures do not exactly correspond to the isobaric lines on the diagram, since the latter refer to saturated air, but for quickly drawing an approximate graph the latter may be used. It should be noted that zero entropy is at 100° Abs., and not 200° as used in the text of this paper and in the tables referred to. Further explanations are given in the text and on the diagram itself. The above is a reproduction of the form used by the British Meteorological Office.)

In the second part of their paper the authors undertake a brief but comprehensive study of the distribution of the meteorological elements in the air masses throughout the regions they have been observing. They attempt also a comparison of the observed facts with the conditions to be anticipated from the Bergen theories. This is too detailed a matter to go into here, but their complete success in explaining all the outstanding phenomena in terms either of the front theory or most plausible local disturbing influences, is worthy of note. The types of weather involved, in general, may be classified in six groups, which, roughly speaking, occur in six latitudinal zones parallel to the front, and are completely explained by the kinds of meteorological activity to be expected at corresponding distances on either side of the front.

One of the most interesting facts brought out in this study of the characteristics of air masses of polar and tropical origin has to do with the distribution of the temperature, or potential energy. Although the author's data from the upper air levels are rather scanty, and local disturbing influences, especially at the mountain stations, are hard to eliminate, they find that up to at least four kilometers in the tropical air masses the isentropic surfaces (surfaces of constant potential temperature) are horizontal, while in the polar air they slope increasingly toward the ground as they approach the front. In the front itself, where the transformation from potential energy to kinetic energy largely takes place, and where, consequently, the center of gravity of the system is sinking, this slope of the isentropic surfaces is, of course, very steep. But the fact that these surfaces are sloping in the polar air and horizontal in the tropical air is in accord with two observed facts in this quite typical case; first, that there are secondary cold fronts or surfaces of discontinuity in the polar air, and second, that the tropical air appears to be continuous and homogeneous. Whether these are characteristic of all air masses of polar and tropical origin, respectively, can not be said without more study.

RESULTS OF AEROLOGICAL OBSERVATIONS MADE AT VARIOUS STATIONS IN THE NETHERLANDS DURING 1924

[Review by L. T. Samuels based on translation by W. W. Reed of the Results of Aerological Observations in 1924. Koninklijk Nederlandsch Meteorologisch Instituut]

Aerological observations by means of aircraft appear to be practicable on 86 per cent to 90 per cent of the days throughout the year. During the summer this percentage rises to 100 while in the winter months it decreases considerably especially during the period from November to February when fog often makes observations impossible for a week at a time. Experience shows that fog is the only condition which entirely prevents such observations. At the De Kooij flying field an unbroken layer of low clouds frequently presents a serious obstacle in the attainment of satisfactory flights on account of the danger in coming down over the sea.

The accompanying table gives the number of airplane observations made at Soesterberg and De Kooij together with the mean and maximum altitudes attained for each month and the year:

		January	February	March	April	May	June	July	August	September	October	November	December	Year
Number observations	Soesterberg	19	22	30	25	31	26	32	27	27	24	27	18	308
	De Kooij	10	15	26	17	19	15	15	13	18	21	10	5	184
Mean altitude (m.) M. S. L.	Soesterberg	4,821	4,588	4,598	4,909	5,345	5,434	5,638	5,514	5,478	5,295	5,276	5,172	5,180
	De Kooij	4,308	1,760	4,976	4,975	4,649	4,722	4,684	4,369	4,269	4,085	4,204	3,433	4,453
Max. altitude (m.) M. S. L.	Soesterberg	5,500	5,063	5,723	5,738	6,108	6,079	5,902	6,088	6,381	5,943	5,837	5,769	6,381
	De Kooij	5,092	5,036	5,204	5,263	5,431	5,384	5,671	6,279	6,525	6,012	5,291	4,987	6,525

This is most certainly a remarkable record of achievement and striking testimony to the practicability of this comparatively new method of observation. At Soesterberg, where the largest number of observations was made, it will be seen that, beginning with May, all of the monthly means were over 5,000 meters, while for July and August they were 5,638 meters and 5,514 meters, respectively. Ascents to over 6,000 meters were made at this station eight times, while 72 per cent of the flights went above 5,000 meters elevation.

Not a single accident occurred at either station in connection with these flights throughout the year. One forced landing owing to the sudden appearance of fog was made safely. A night airplane observation, made at De Kooij at 10 p. m. on March 10th and reaching an altitude of 4,526 meters, is deserving of special notice.

Seven sounding balloons were released during the year. Five of the instruments were recovered, all of which reached the stratosphere. In one of these cases, however, the clock stopped before the stratosphere was reached. The remaining four indicated the altitude and temperature of the base of the stratosphere to be as follows: March 19, 8,801 meters, −58.5° C.; May 23, 10,063 meters, −48.6°; May 25, 8,629 meters, −50.2°; July 19, 9,220 meters, −50.2°. The maximum altitude reached in this series of sounding balloon observations was 18,605 meters at which elevation the temperature was −48.7° C., on May 25.

Owing to the illness of the personnel only 13 kite flights were made during the year at Duin-dal. These reached an average altitude of 1,281 meters, the maximum being 1,564 meters.

Pilot balloon observations were made in general twice daily with occasionally three observations daily in summer. At De Bilt 436 observations were made of which 290 were followed up to over 1,500 meters, 110 to 4 kilometers, 56 to 6 kilometers, 33 to 8 kilometers, and 14 to 10 kilometers. The maximum altitude was 13.7 kilometers reached on May 27. At De Kooij the number of pilot balloon observations was 279, of which 157 reached an elevation of over 1,500 meters.

The above data are given in very complete and excellently arranged tables for convenient use of the investigator. No discussion is made, however, of the observational data appearing in the tables.